NOTES ON THE JULY 1932 MEETING OF THE COMMITTEE ON SYMBOLS, UNITS, AND NOMENCLATURE OF THE INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS, TO DISCUSS MAGNETIC UNITS

By Arthur E. Kennelly*

Purpose and Scope—The purpose of this communication is to lay before readers of Terrestrial Magnetism and Atmospheric Electricity an unofficial historical outline of the international actions on C. G. S. magnetic units during the last five years, up to and including those of the Committee on Symbols, Units, and Nomenclature (S. U. N. Committee) at its recent meeting in Paris, July 9, 1932,—together with certain deductions that seem to follow therefrom. For more precise and authentic information, reference may be made to the official minutes of these various meetings, which are too lengthy to be included here.

Brief historical outline of C. G. S. magnetic units up to 1925—Gauss showed in 1833 how to reduce terrestrial magnetic observations with suspended magnets to absolute measure, that is, to units of length, mass, and time. Weber, cooperating with him, extended the scope of these researches in 1840 and 1851. They employed the millimeter-milligram-second (M. M. S.) system. Magnetic observatories began to keep records in these units about 1845. The rapid growth of electric telegraphy in 1860, created a demand among telegraph engineers for electrical units. At a meeting of the British Association for the Advancement of Science (B. A.) in 1861, a paper was presented by the telegraph engineers Clark and Bright, pointing out the need for scientific measurements and units in that field. The first B. A. committee was then appointed to report upon "Standards of electrical resistance." It issued several annual reports and continued until 1867. It recommended the adoption of units in the meter-gram-second (M. G. S.) absolute system. It issued standard B. A. resistance-coils, and standard condensers in that system, as *ohms* and *microfarads*, respectively. It proposed the *volt*, approximately at its present unit magnitude; but did not reach the stage of issuing standards of electromotive force.

The second B. A. committee was appointed for "The selection and nomenclature of dynamical and electrical units." It presented its first report in 1873. It adopted the B. A. standard *ohm*, *volt*, and *farad* of the first B. A. committee, but changed its basic system from the M. G. S. to the C. G. S. (centimeter, gram, and second). It extended the scope of the latter system to include a number of physical sciences.

The *volt*, *ohm*, and *farad*, as decimal derivatives of the C. G. S. system of magnetic units, with their corresponding B. A. standards, continued to find favor and extended use. They first received international adoption at the Paris Congress of 1881. That Congress adopted the C. G. S. system, with the *ohm* and *volt* as its decimal derivatives. The *ampere*, *coulomb*, and *farad* were adopted from unitary relations with the *ohm* and *volt*. An international commission was charged with the determination of the standard mercury-column resistance embodying the *ohm*. That commission reported in 1884.

The second International Electrical Congress at Paris, in 1889, added to the series of practical units three more, namely, the *joule*, *watt*, and *quadrant* (subsequently renamed the *henry*), as decimal derivatives of the corresponding C. G. S. units.

In 1891, a Committee on "Units and standards" (U. & S.) of the American Institute of Electrical Engineers (A. I. E. E.), recommended that at the next international electrical congress (Chicago, 1893), four magnetic units should be adopted in the practical series, and given names: For magnetomotive force, 10^{-1} C. G. S. unit or $1/4\pi$ ampere-turn; for magnetic flux, 10^8 C. G. S. unit; for flux-density, 10^8 C. G. S. unit of flux per square centimeter; and for reluctance 10^{-9} C. G. S. unit. No names were suggested in the report, which was accepted, printed, and brought to the attention of the Chicago Congress.

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At the International Electrical Congress of Chicago in 1893, the question of magnitudes and names in the volt-ampere-ohm series, to magnetic units, was (1—see bibliography at end of article) discussed in the Chamber of Delegates. The Congress recommended that for magnetic units, the C. G. S. system should be used, and that for the present, no names should be given to them.

In view of this recorded decision of the Chicago Congress, the U. & S. Committee recommended to the A. I. E. E. in November 1893, the provisional adoption of names for four C. G. S. magnetic units: The *gilbert* for magnetomotive force $\mathfrak{F}$, the *weber* for flux Φ, the *oersted* for reluctance $\mathfrak{R}$, and the *gauss* for flux density B. This recommendation was adopted, and the American delegation to the next following Congress of 1900, was instructed to favor their adoption, and also to recommend international consideration of rationalising the C. G. S. magnetic units (making the unit of mmf. equal to the *abampere-turn* instead of the 4πth part of an *abampere-turn*).

At the Paris Congress of 1900, it was decided not to consider rationalising the C. G. S. magnetic units, and only to give names to two of them, namely, the *maxwell* for flux Φ, and the *gauss* for magnetic field intensity H. There was some misunderstanding in the meeting and some of the delegates understood that the *gauss* was adopted (3) for flux-density B, until the Minutes (2) of the meeting were published.

The International Electrical Congress of 1904, next following, in St. Louis, itself took no action in regard to electric or magnetic units, but recommended that in future, international actions in electrical matters should be divided between two international bodies: One, later called "The International Conference on Electrical Units," consisting of government delegates, which dealt especially with the electrical national standards maintained by legislative authority, and the other, "The International Electrotechnical Commission" (I. E. C.), a permanent body, organised in 1906 by Col. R. E. Crompton, and with its General Secretariat in London. The I. E. C. dealt especially with the standardisation of electrical machinery; but one of its advisory committees—No. 1 on "Nomenclature"—has for a long period discussed units, standards, symbols, and definitions. The I. E. C. also authorises the holding of international electrical congresses.

Since 1900, no international congress has attempted to formulate decisions in regard to electric or magnetic units; but ambiguity and confusion have steadily increased in the magnetic literature of all countries, over the meanings, symbols, and formulas of certain magnitudes and their units, especially as regards the *gauss*. Some writers have used this name for the unit of magnetising force H, others for that of flux-density B; and still others for both H and B indiscriminately. Moreover, some text-books have maintained that H and B stand for physically identical quantities, under which assumption, of course, the *gauss* would be applicable to both. Other text-books have declared that in any magnetic circuit, H and B represent physically different quantities, in which case the name *gauss* might be applied to the unit of one, but not to that of the other. In no country's magnetic literature has this confusion been entirely absent. To those who held B and H to be identical, their ratio B/H, the permeability μ of a magnetic-circuit medium, or even μ_0 the permeability of vacuum and free space, became a mere numeric or "dimensionless" quantity, while to those who held B and H to be essentially different, or to have different physical dimensions, μ and μ_0 were not mere numerics, but likewise had dimensions of some kind. From an engineering standpoint, the dimensions assigned to permeability may not be important; but from the standpoint of unitology, it is manifestly desirable that the definitions and meanings of these terms and symbols should be internationally standardised. It is generally admitted on both sides of this controversy—now more than thirty years old—that there are logical definitions in the text-books of leading authorities which will support either hypothesis. That is, there are certain authentic definitions under which B and H become identical quantities, with μ a mere number, and again other authentic text-books with definitions under which B and H are physically different, with μ a non-numeric.

I. E. C. actions at the meetings of Bellagio and Oslo—No international action was taken on this vexed question of the *gauss*, until 1927, when the I. E. C. at its eighteenth plenary meeting, in Bellagio, Italy, discussed certain proposals on magnetic units, and appointed an international subcommittee (5) representing seven countries, to consider and report upon the matter. This subcommittee was later enlarged to represent twelve countries, as Section B of No. 1 Advisory Committee on Nomenclature, dealing with electric and magnetic magnitudes and units (E. M. M. U.)

The E. M. M. U. Committee worked for a year by correspondence, without success. There was so much difference of opinion and usage in the different countries, that no agreement on magnetic units was possible. The committee reported (7) in 1929, that the subject of magnetic units should be agitated in the various countries and should be placed on the agenda of the next I. E. C. meeting, to be held in Scandinavia in the following year.

The E. M. M. U. Committee, meeting in Scandinavia June-July 1930, decided that the first necessity for international agreement was to arrive at a convention as to whether permeability μ should be accepted as having real dimensions or not. After some discussion, it was unanimously agreed that for electrotechnical purposes, B and H should be taken as representing different quantities, and with their ratio μ as having dimensions. Accordingly, the *gauss* could only be accepted as applying to one of the pair. It was recommended to assign it to flux-density B, and in order to indicate that, in the opinion of the committee, the name *gauss* should not be applied to magnetising force H, the unit name *oersted* was selected for H. The *maxwell* of 1900 was then reaffirmed, and the *gilbert* recommended for the unit of magnetomotive force $\mathfrak{F}$ (mmf). These decisions, all either unanimous, or voted by a considerable majority of the representatives of ten countries, were reported to the plenary meeting of the I. E. C. at Oslo, in July 1930, and the report was unanimously adopted. Table 1 shows the units, unit names, and symbols recommended by the E. M. M. U. Committee.

TABLE 1—*Magnetic units in the classical C. G. S. magnetic system, internationally adopted by the Oslo I. E. C. meeting of 1930*

Recommended name	For C. G. S. magnetic unit of	Symbol
Maxwell	Magnetic flux or flux of magnetic induction	Φ
Gauss	Flux-density	B
Oersted	Magnetic field-strength, magnetic intensity, or magnetising force	H
Gilbert	Magnetomotive force	$\mathfrak{F}$

The committee also made recommendations in regard to other matters of unitology outside of the C. G. S. system, which need not here be considered. Reference may be made to the E. M. M. U. (8) Minutes, I. E. C. Document 77.

Action of the E. M. M. U. Committee in London 1931—In view of certain criticisms of the actions at Oslo that appeared after that meeting in the electrotechnical journals, it was decided to hold another meeting of the E. M. M. U. Committee at London, in September 1931, to review the recommendations already made.

In July 1931, the International Union of Pure and Applied Physics, (I. P. U.), at its meeting in Brussels, established (12) a Committee on Standards, Units, and Nomenclature (S. U. N.), under the chairmanship of Sir Richard Glazebrook, F.R.S. The S. U. N. Committee was invited and requested by the I. E. C. to aid in arriving at complete international agreement on magnetic units, after consulting the views of physicists in different countries. The S. U. N. Committee accepted the request. Three of its members attended the London meeting of the E. M. M. U. Committee, which was held in September 1931. It was unanimously voted at that meeting by representatives of eight I. E. C. national committees (two other countries not voting), to endorse the recommendations concerning C. G. S. magnetic units made at Oslo in the preceding year, and to leave those recommendations undisturbed (I. E. C. Document R. M. 97—see 13).

Actions of the S. U. N. Committee at Paris in 1932—The S. U. N. Committee met at Paris July 9, 1932, under the chairmanship of Sir Richard Glazebrook, and with Dr. E. Griffiths as Secretary. Eight countries were represented by nineteen persons in all. The Committee had already received and tabulated replies to a questionnaire (14) on the subject of electric and magnetic units, which it had issued in December 1931. Votes were taken at the meeting, not by countries but by representatives present, on eight propositions appearing on the agenda. So far as concerns C. G. S. magnetic units, here under consideration, the meeting adopted the following propositions, either unanimously, or by a considerable majority.

(*A*) The C. G. S. system of units is suitable for the physicist.

(*B*) The following Table 2 of magnetic units is acceptable:

TABLE 2—*C. G. S. units accepted by the S. U. N. meeting in Paris 1932*

Quantity designated	Symbol	Defining equation	Name
Flux	Φ	$d\Phi/dt = -E$	Maxwell
Induction or flux-density	B	$\int B\, dS = \Phi$	Gauss
Magnetomotive force round a circuit	F	$F = 4\pi NI$	Gilbert or oersted. cm.
Magnetising force or field-strength	H	$\int H.\cos \epsilon\, ds = F$	Oersted*
Permeability	μ	$\mu = B/H$	Permeability

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*Messrs. Tuve and Hafstad of the Department of Terrestrial Magnetism have made very appropriately the following query: "The old unit for reluctance R was the oersted; now that this name is taken for H, what about reluctance?" Unfortunately, no substitute name for the C. G. S. unit of reluctance has been adopted, up to this date. The *oersted* has been taken away for H and nothing has been put in its place. At first, it was thought we should try to secure a new name for the C. G. S. unit of reluctance, and I think that it is generally agreed that such a name would be desirable. There is, however, still so much turbulence in the magnetic world over the main questions involved, that it seems better, for the present, to defer this question for a few years. There is good prospect of our having the main questions settled beyond dispute in Chicago in June 1933. Then, perhaps, the way will be open for dealing with reluctance.—*A. E. K.*

(*C*) That B and H are quantities of different nature.

(*D*) The factor $4\pi/10$ should be retained in the definition of magnetomotive force.

It will be seen that this S. U. N. table of C. G. S. units is in all essentials the same as the I. E. C. table of Oslo, and that the C. G. S. classical system, as adopted at Paris in 1881, should be retained unchanged and without rationalisation. The Oslo convention also endorsed that B and H should be taken as different physical quantities, with their ratio μ, the permeability, as a non-numeric.

The following proposition was also adopted:

(*E*) The system of magnetic units may be based on the following two methods as alternatives: (*a*) The force between two elementary magnetic poles (coulomb), and (*b*) The force between two elements of current (ampère). Dr. H. Abraham, the General Secretary of the I. P. U., was also requested by the Meeting to prepare for consideration by the Commission a preliminary report on the Fundamental Units.

Deductions that seem to follow from the I. E. C.-I. P. U. actions (1930-1932)—The preceding historical outline of international actions on C. G. S. magnetic units having been carried up to and including July 1932, the following suggestions are made by the writer, as personal opinions.

From the foregoing historical outline, it will be seen that serious divergences in symbols, terms, and definitions had taken root in world magnetic literature since 1900, at least. In this confusion, no middle ground or compromise was possible. The I. E. C. and I. P. U. have, however, agreed upon a majority convention, through which agreement can be maintained: First by accepting the theory that B and H represent different physical quantities, with the *gauss* assigned to the former, and either the *gilbert per cm* or the *oersted* to the latter; second, that space-permeability μ_0 and likewise the absolute permeability μ of a magnetic medium have like dimensions; and third, that relative permeability μ/μ_0 of a magnetic medium is a mere numeric.

The literature of terrestrial magnetism encounters a special ambiguity to clear up, but at the same time finds a special loophole for escape from the past confusion. It has not only used the *gauss* as the unit of intensity of magnetic field H; but has also very generally used the name *gamma*, with the Greek symbol γ, for 10^{-5} *gauss*, by mutual agreement between the various magnetic observatories, as a convenient size of subdecimal in which to express terrestrial-magnetic observations. There has been no suggestion, however, of making any change in the meaning of the *gamma*, which remains applicable to the unit in the fifth decimal place of H. When it is necessary to specify the unit of H itself, according to the new convention, it should be written either as the C. G. S. unit of H, or as the *gilbert per cm*, or as the *oersted*.

Just as the fundamental C. G. S. magnetic formula for electromechanical force exerted by an electric field H_e on a point-charge e, is in dynes

$$f = H_e e \qquad (1)$$

where H_e is the local gradient of electric potential in abvolts/cm—that is, in C. G. S. magnetic units of electric potential per cm, and e is in abcoulombs, or C. G. S. magnetic units of charge—so the fundamental formula for magnetomechanical force exerted by a magnetic field H on a point-pole m is in dynes

$$f = Hm \qquad (2)$$

where H is the local gradient of magnetic potential in gilberts/cm and

m is the strength of the pole or the "quantity of magnetism" on its surface, one pole unit giving emergence to 4π maxwells of magnetic flux.

Air, at ordinary pressures and temperatures, being a feebly magnetisable gaseous medium, will have a permeability in C. G. S. magnetic units (abhenries/cm)

$$\mu = \mu_0 + 4\pi\kappa \tag{3}$$

where μ_0 is space-permeability, taken as unity in the C. G. S. magnetic system, and κ is the magnetic susceptibility of the medium. For standard atmospheric pressure, and 20° C, κ is given as 2.9×10^{-8}. Hence from (3), $\mu = 1.00000036$ or the flux-density B will not exceed the magnetising force H by more than about one part in three millions, a correction too small to be taken into account for the present degree of precision attainable in magnetic measurements. A field of $H=1$ *oersted* or 1 *gilbert/cm*, or 100,000 *gammas*, would thus give rise to a flux-density B of 1.000000 *gauss* in the air. As a matter of convention, however, if the Earth's magnetic field were measured with a non-magnetic rotating coil or earth inductor, instead of with a freely suspended magnet, the quantity evaluated would be the flux-density B in the air, and not the magnetising force H.

If the coil has N equal parallel turns, each enclosing an active area of S cm², the maximum cyclic magnetic flux linked with the coil, in a plane perpendicular to its rotation axis, would be in *maxwells*

$$\Phi = S\,N\,B = S\,N\,\mu\,H \tag{4}$$

and with a uniform rotational angular velocity ω radians/sec, the maximum cyclic electromotive force E_m induced in the coil would be in *abvolts*

$$-E_m = \mathrm{d}\Phi/\mathrm{d}t = S\,N\,(\mathrm{d}B/\mathrm{d}t) = S\,N\,B\,\omega \tag{5}$$

The effective, or root-mean-square value E, of this alternating electromotive force is in *abvolts*

$$-E = -E_m/\sqrt{2} = S\,N\,B\,\omega/\sqrt{2} \tag{6}$$

and in *gauss*

$$B = -E\sqrt{2}/S\,N\,\omega \tag{7}$$

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(4) F. A. Wolff, The so-called international electrical units, *Trans. Internat. Electr. Cong. St. Louis*, 1904, **1**, 148-169.

(5) Rapport général des réunions tenues à Bellagio, Sept. 1927, *I. E. C.* Fasc. 49, 185 pp.

(6) A. E. Kennelly, Historical outline of the electrical units, *Proc. Soc. Promotion Eng. Education*, **19**, No. 3, 229-275 (1928).

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(8) I. E. C., Report of the plenary meeting at Oslo, July 1930; also I. E. C. Document R. M. 77, *Adv. Comm. No. 1 on Nomenclature*, Unconfirmed minutes of meetings held in Stockholm, June 30-July 5, 1930.

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(12) Meeting of International Union of Pure and Applied Physics, Brussels, July 1931.

(13) I. E. C. Document No. R. M. 97, *Adv. Comm. No. 1 on Nomenclature*, Unconfirmed minutes of meeting held in London, Sept. 18, 1931.

(14) Questionnaire on electrical units issued by S. U. N. Committee of Internat. Union of Pure and Applied Physics, December 1931, 2 pp.

(15) Louis Loly, L'état actuel de la question des unités électriques et magnétiques, *Cong. Internat. Electr.*, Paris 1932, Rapport No. 1, 2nd. Section, 17 pp.

(16) A. Cotten, Sur les noms des unités magnétiques, *Cong. Internat. Electr.*, Paris 1932, Rapport 1 C-2, 2nd. Section, 7 pp.

(17) International critical tables, **6**, 354, Table 1 (1929).

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REMARKS ON DR. KENNELLY'S NOTES

By J. Bartels

The readers of this Journal will be grateful to Dr. Kennelly for his clear summary. He stresses the usefulness of the international conventions for a uniform adoption of units—a usefulness which is rather independent from theoretical considerations about which there is no unanimity.

As to terrestrial magnetism it is a question whether the new conventions, especially the rather vague recognition of a physical dimension of the magnetic permeability, make a change in the usual practice necessary. I should like to support the unchanged use of the *gauss* (and of the γ as its 100000th part) as a unit even more strongly than Dr. Kennelly, for the following reasons: Practically all writers of text-books or papers on terrestrial magnetism neglected from the outset the susceptibility of air, a procedure fully justified by the negligible numerical difference between B and H, as Dr. Kennelly also points out. Thus, if we speak of the magnetic *field* of the Earth and of its intensity, we need not state definitely whether we mean the quantity which the convention calls magnetic field-strength H, or that which it calls flux-density B. (Furthermore, it is usual in terrestrial magnetism—and sanctioned by the International Meteorological Conference at Paris in 1896—to reserve the letter H for horizontal force. We therefore may as well talk of the total force or total intensity of the north component, etc., and express them in the unit gauss, as heretofore. A physicist adhering to the conventions is at liberty to take the values as expressing "flux-density".) As Dr. Kennelly states, with the electric magnetometers —for instance, the Schuster-Smith magnetometer—measurements are in fact made in the unit gauss as defined by the new international conventions.

As characteristic of the (justified) promiscuous use of H and B by workers in terrestrial magnetism, I translate a short passage by Adolf

Schmidt (Enzyklopädie d. mathem. Wissenschaften **6**, 1, *B*, p. 382, Leipzig, 1918): "Starting from the rather strong paramagnetism of oxygen, which he had discovered, and from its noticeable change with temperature, Faraday attempts to attribute the diurnal (magnetic) variation to a deformation of the lines of force of the Earth's field, connected with the heating and cooling of the atmosphere. Such an effect exists, of course, but it is far too small to be noticeable." This seems to indicate the conception of the "field" as flux-density. This point, however, has never been stressed because, until quite recently, in the German physical literature, H and B have been regarded as having the same dimensions, and μ has been regarded as a pure number—practically unity in air.

There is also an instrumental reason why it is inopportune to stress the difference between B and H in terrestrial-magnetic measurements: The "non-magnetic" materials, such as copper, marble, and wood, of which magnetic instruments consist, have all a (numerically) higher susceptibility than air; nevertheless it is neglected, and with good reason. Further, it is not at all clear (though unimportant), what the usual methods of measuring horizontal intensity would yield numerically in an evacuated room of a given shape, provided they could be used with sufficient accuracy. Finally, taking the conventions strictly, we ought to "reduce" the data from Huancayo, for instance, for the lower pressure and susceptibility of the air there, if we really wished to express the field in oersteds.

In short, there is no important reason why we should discontinue the established practice of talking of terrestrial-magnetic forces, for instance, the north component X, as expressed in gauss. Only in such cases where the susceptibility is high enough, so that the permeability deviates appreciably (by more than one-thousandth of one per cent) from the value in vacuum, the discrimination between flux-density B and field-strength H is essential. Such cases will occur, so far as terrestrial magnetism is concerned, mainly in instrumental questions, or in the interpretation of rock-magnetism, but will hardly enter into routine observatory or field work.

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[Note—With reference to Dr. Kennelly's article it is to be particularly noted that the distinctions he indicates between the quantities B and H must be taken account of in certain experimental researches in terrestrial magnetism, for example, on rocks. So far as general measurements of the Earth's field are concerned, and as Dr. Kennelly remarks, the distinction is of no practical consequence because the error arising in the usual practice followed in terrestrial magnetism is much within the highest attainable accuracy, using equipment of best present design. Dr. Kennelly's article makes concise record of the historical development of magnetic units and their relation to terrestrial-magnetic research. Under the circumstances so clearly enumerated by him and by Dr. Bartels the interests and viewpoint of the magnetician need involve no prolonged discussion or unitological controversy.—*Ed.*]